

III. An Ophthalmic Electrochemical Analyte Sensor

[0068] FIG. 3 is a functional block diagram of a system 300 for electrochemically measuring a tear film analyte concentration. The system 300 includes an eye-mountable device 310 with embedded electronic components powered by an external reader 340. The eye-mountable device 310 includes an antenna 312 for capturing radio frequency radiation 341 from the external reader 340. The eye-mountable device 310 includes a rectifier 314, an energy storage 316, and regulator 318 for generating power supply voltages 330, 332 to operate the embedded electronics. The eye-mountable device 310 includes an electrochemical sensor 320 with a working electrode 322 and a reference electrode 323 driven by a sensor interface 321. The eye-mountable device 310 includes hardware logic 324 for communicating results from the sensor 320 to the external reader 340 by modulating (325) the impedance of the antenna 312. Similar to the eye-mountable devices 110, 210 discussed above in connection with FIGS. 1 and 2, the eye-mountable device 310 can include a mounting substrate embedded within a polymeric material configured to be mounted to an eye. The electrochemical sensor 320 can be situated on a mounting surface of such a substrate proximate the surface of the eye (e.g., corresponding to the bio-interactive electronics 260 on the inward-facing side 232 of the substrate 230) to measure analyte concentration in a tear film layer interposed between the eye-mountable device 310 and the eye (e.g., the inner tear film layer 40 between the eye-mountable device 210 and the corneal surface 22).

[0069] With reference to FIG. 3, the electrochemical sensor 320 measures analyte concentration by applying a voltage between the electrodes 322, 323 that is sufficient to cause products of the analyte catalyzed by the reagent to electrochemically react (e.g., a reduction and/or oxidization reaction) at the working electrode 322. The electrochemical reactions at the working electrode 322 generate an amperometric current that can be measured at the working electrode 322. The sensor interface 321 can, for example, apply a reduction voltage between the working electrode 322 and the reference electrode 323 to reduce products from the reagent-catalyzed analyte at the working electrode 322. Additionally or alternatively, the sensor interface 321 can apply an oxidation voltage between the working electrode 322 and the reference electrode 323 to oxidize the products from the reagent-catalyzed analyte at the working electrode 322. The sensor interface 321 measures the amperometric current and provides an output to the hardware logic 324. The sensor interface 321 can include, for example, a potentiostat connected to both electrodes 322, 323 to simultaneously apply a voltage between the working electrode 322 and the reference electrode 323 and measure the resulting amperometric current through the working electrode 322.

[0070] The rectifier 314, energy storage 316, and voltage regulator 318 operate to harvest energy from received radio frequency radiation 341. The radio frequency radiation 341 causes radio frequency electrical signals on leads of the antenna 312. The rectifier 314 is connected to the antenna leads and converts the radio frequency electrical signals to a DC voltage. The energy storage 316 (e.g., capacitor) is connected across the output of the rectifier 314 to filter high frequency noise on the DC voltage. The regulator 318 receives the filtered DC voltage and outputs both a digital supply voltage 330 to operate the hardware logic 324 and an analog supply voltage 332 to operate the electrochemical sensor 320. For example, the analog supply voltage can be a

voltage used by the sensor interface 321 to apply a voltage between the sensor electrodes 322, 323 to generate an amperometric current. The digital supply voltage 330 can be a voltage suitable for driving digital logic circuitry, such as approximately 1.2 volts, approximately 3 volts, etc. Reception of the radio frequency radiation 341 from the external reader 340 (or another source, such as ambient radiation, etc.) causes the supply voltages 330, 332 to be supplied to the sensor 320 and hardware logic 324. While powered, the sensor 320 and hardware logic 324 are configured to generate and measure an amperometric current and communicate the results.

[0071] The sensor results can be communicated back to the external reader 340 via backscatter radiation 343 from the antenna 312. The hardware logic 324 receives the output current from the electrochemical sensor 320 and modulates (325) the impedance of the antenna 312 in accordance with the amperometric current measured by the sensor 320. The antenna impedance and/or change in antenna impedance is detected by the external reader 340 via the backscatter signal 343. The external reader 340 can include an antenna front end 342 and logic components 344 to decode the information indicated by the backscatter signal 343 and provide digital inputs to a processing system 346. The external reader 340 associates the backscatter signal 343 with the sensor result (e.g., via the processing system 346 according to a pre-programmed relationship associating impedance of the antenna 312 with output from the sensor 320). The processing system 346 can then store the indicated sensor results (e.g., tear film analyte concentration values) in a local memory and/or a network-connected memory.

[0072] In some embodiments, one or more of the features shown as separate functional blocks can be implemented ("packaged") on a single chip. For example, the eye-mountable device 310 can be implemented with the rectifier 314, energy storage 316, voltage regulator 318, sensor interface 321, and the hardware logic 324 packaged together in a single chip or controller module. Such a controller can have interconnects ("leads") connected to the loop antenna 312 and the sensor electrodes 322, 323. Such a controller operates to harvest energy received at the loop antenna 312, apply a voltage between the electrodes 322, 323 sufficient to develop an amperometric current, measure the amperometric current, and indicate the measured current via the antenna 312 (e.g., through the backscatter radiation 343).

[0073] FIG. 4A is a flowchart of a process 400 for operating an amperometric sensor in an eye-mountable device to measure a tear film analyte concentration. Radio frequency radiation is received at an antenna in an eye-mountable device including an embedded electrochemical sensor (402). Electrical signals due to the received radiation are rectified and regulated to power the electrochemical sensor and associated controller (404). For example, a rectifier and/or regulator can be connected to the antenna leads to output a DC supply voltage for powering the electrochemical sensor and/or controller. A voltage sufficient to cause electrochemical reactions at the working electrode is applied between a working electrode and a reference electrode on the electrochemical sensor (406). An amperometric current is measured through the working electrode (408). For example, a potentiostat can apply a voltage between the working and reference electrodes while measuring the resulting amperometric current through the working electrode. The measured amperometric current is wirelessly indicated with the antenna (410). For example,